Radiobiological Concepts for Manned Space Missions

John E. Pickering

USAF School of Aerospace Medicine, Brooks Air Force Base, Texas 78235

Pickering, J. E. *Radiobiological concepts for manned space missions.* Aerospace Med. 41(2):159-165. 1970.

Carefully established premission planning doses and maximum operational dose limits are clearly enhanced by clinical judgments when go-no-go decisions are made in the event of an astronaut's exposure to ionizing radiation. The very nature of extended lunar missions (exploration) and long duration low earth orbit missions are clear cases for evaluating man's clinical response before go-no-go decisions are made. There are well identifiable decision points in mission plans that are best judged by clinical responses if the mission is to avoid performance decrement at critical times, i.e., at the peak of astronaut activity: descent, EVA, ascent, rendezvous, transfer, etc. Careful on-board monitoring of the astronaut's condition and judicious recording and interpretation of actual radiation manifestations with respect to time can and should dissuade premature or unfounded decisions. This philosophy has its greatest merit if one accepts the tenet that man is in the system to make observational judgments and assessments.

SPACE RADIATION PLANNING CRITERIA

The human responses attendant to the radiation risks from manned space flight can be more reasonably identified and interpreted in developing radiation dose concepts as a result of the Space Science Board's review of *Radiobiological Factors in Manned Space Flight.*[4] This approach recognizes the limits of the available data, indicates deficiencies in our knowledge, and clearly leaves the user with the responsibility for developing and justifying his own standards based upon the unique operating problems of each given space mission.

Thus, there is no single set of "permissible dose" values, but rather there is the admonition to balance the risk of radiation exposure against what is to be gained with each mission and/or program.

GENERAL CONSIDERATIONS

Before such judgments are attempted, certain general considerations can and should be viewed against the backdrop of each specific mission to be studied:

1. The upper radiation exposure limits should be as low as possible and consistent with economic and practical applications—risk versus gain.
2. No single set of "permissible dose" values will have universal application, nor should they be adopted.
3. There are acute (early) and delayed (latent) effects to consider of both somatic (the exposed person) and genetic (progeny) interest.
4. The space radiation environment is indeed different from that on the ground (natural and simulated).
5. Biological effects of radiation are a function of dose, dose rate, energy, and the type of radiation.
6. Dose protraction, fractionation, recovery rates, and residual damage likewise modify radiation response; such modifications can vary with 5. above.
7. The radiation problem is different in degree and time of response in terms of a low earth orbit, a highly elliptical orbit, a synchronous orbit, and interplanetary (lunar distance) travel—the most likely manned missions of this next decade.
8. Biological variability among different individuals can be a factor of 2 in terms of dose response (that is to say, 200 rads may produce a dose response similar to that of 100 rads in one person while another individual with the same 200 rad dose may respond as if he had received 400 rads).
9. Generalized biological response patterns following exposure to laboratory radiation sources very likely are the same for space radiation exposures (but not all of the space environment can be simulated on earth and certainly not in a composite operational mode), i.e., radiation plus 0 gravity, thermal pulses, or vibration.

Thus, one is enjoined to develop dose criteria with the full knowledge that there is some finite risk involved. This is not, of course, without its dividends for it is only in this way that more precise information will be obtained to permit refined judgments.

The criteria for the diagnosis and prognosis of radiation injury are difficult because the injury may not be immediately manifest and because some of the symptoms may be due to other causes. Nevertheless, the

The views expressed in this paper are those of the author and do not reflect the official views of the National Aeronautics and Space Administration or of the Air Force.

9

classical "radiation syndrome" for early radiation effects is a logical point of departure. In the time frame of 60 or less days, the period accepted as sufficient to demonstrate *acute effects,* the pertinent symptoms could be: malaise, nausea, vomiting, erythema, iritis, epilation, oropharyngeal lesions, gingivitis, hemorrhage, diarrhea, bloody diarrhea, fever, and hematologic depression as demonstrated by a change in lymphocytes at 2 to 3 days; a drop in platelets at about 3 weeks; and a drop in neutrophils at about 5 weeks (Figure 1). Similarly, the time course with respect to dose can be reasonably identified as a guide to specific mission planning (Figures 2 and 3).

On the basis of these relationships (effects versus dose and time of onset), specific mission profiles can be discussed against the radiation environment, possible sequelae, and the doses required for such cases.

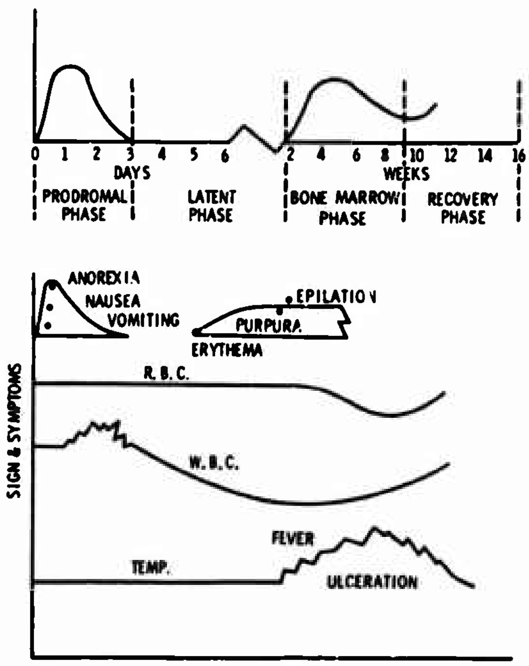

Fig. 1. Phases of the acute radiation syndrome.

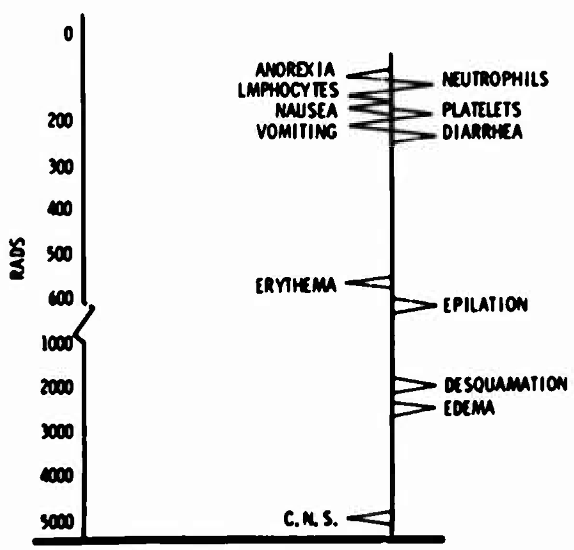

Fig. 2. Effect vs. dose.

MISSION PROFILES

Low Earth Orbit—Non-Polar (200 n.m.)

The radiation environment in this case has some experimental definition from the biological and physical points of view (Gemini)[5] (Apollo),[8] and as a consequence there is little conjecture. As a corollary, this region is less hostile in the sense that there is some constancy to the radiation factors, barring future high altitude nuclear detonations with the subsequent trapping of fission process beta particles.

Dose criteria factors:

1. Galactic background—essentially single events to cells, .01 rad/day.
2. South Atlantic Anomaly—protons, electrons, beta particles, bremsstrahlung, ≈ 100 mrads/hour (≈ 25 mrads/orbit).
3. Quality factor for all these radiations ≈ 1 at the energies measured.
4. Nonuniform dose distribution (lessens effects).
5. Protraction of exposure—tends toward lowered dose rate for average rate on each orbit.

In this case, depending on the shielding factors, the greatest contribution to dose is from the radiation in the South Atlantic Anomaly, ≈ 100 mrads/hour (25 mrads/orbit). Even where the orbit is elliptical and more time is spent near the center of the anomaly, there is opportunity to fly for periods of 60 days or more.

Elliptical and Highly Elliptical Orbits

These orbits would most likely be used only if rescue, interception, negation, repair, etc., was required. They are otherwise forbidden zones for long duration flights in the foreseeable future.

Dose criteria factors: (Table II)

1. Galactic background—.01 rad/day.
2. South Atlantic Anomaly—(variable)—0.3-0.6 rad/day.

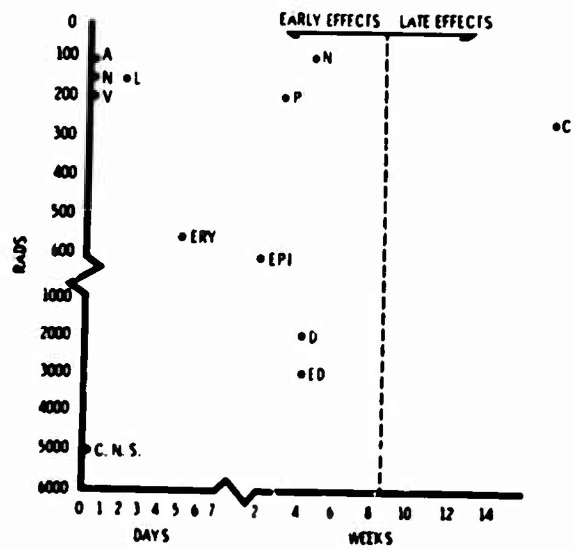

Fig. 3. Acute Effects vs. Dose vs. Time of Onset. In "Days" section: A—Anorexia, N—Nausea, L—Lymphocytes, V—Vomiting, ERY—Erythema; In "Weeks" section: N—Neutrophils, P—Platelets, C—Cataracts after 16 weeks, EPI—Epilation, D—Desquamation, ED—Edema.

3. Inner Van Allen Belt—(variable)—6-8 rad/day—1-1.5 rad/orbit.
4. Outer Van Allen Belt and alpha particles—(variable)—2.2 rad/day.
5. Quality factor varies from 1, depending on radiation types.
6. Dose protraction in the sense of varying dose rates would obtain although the environment would be more constant and tend toward higher average dose rates.

In these cases, elliptical and highly elliptical depending on shielding, the greatest contribution to dose is the inner Van Allen Belt (mostly protons above 40 MeV) and bremsstrahlung.

These cases are ones in which a great deal more information is required before stay times are established. Information on the physical environment is currently being obtained on an OV3-4 satellite and should be readily applicable.[8]

Depending on the measurements taken from the OV3-4, particularly on the energy spectrum of electrons and protons, this could be a forbidden zone for 60 or more days of orbital stay time, particularly if the orbit is highly elliptical with apogee between 2000 and 5000 miles. The temporal and spatial variation of both the inner and outer belts appears to be difficult to assess so that the exact contribution of protons and electrons is conjectural, and both the skin dose and bone marrow dose could be significant.

Synchronous Orbit

Dose criteria factors: (Table II)
1. Galactic background—.01 rad/day.
2. Outer Van Allen Belt, mostly electrons—(variable) 2.2 rad/day.
3. Inner Van Allen Belt penetration before synchronous orbit is established—1-2 rad.
4. Quality factor—variable in this case (protons, electrons, alphas, secondaries).
5. Essentially no protraction or fractionation.
6. Nonuniform dose distribution (this would likely tend to normalize in 60 days).
7. Bremsstrahlung will be a significant dose factor in this case.
8. Alpha particles of 5 to 85 MeV can contribute significantly to skin dose (if a flare occurs).
9. Solar flares must be considered, particularly if a second flare closely follows a first flare event—any umbrella effect is lost.

Information on which to make refined judgments can best be determined after the Applications Technology Synchronous Satellite data are reduced. The radiations are primarily electrons and would constitute in the main a skin dose problem. Secondaries would be the major source of tissue depth dose. It is in this regime where shielding could really prove significant. To avoid extreme weight penalties from shield materials, it is possible to consider the use of water in water-cooled undergarments, as well as apron type devices similar to radiologists' aprons. It is possible in this way to gain fractions to near 1 gm/cm^2 of additional shield for just a few pounds, thereby extending stay times without undue weight penalties. (See Figures 4[1] and 5[7].)

Lunar Mission of Short Duration (7 to 8 days)

Dose criteria factors:
1. Galactic background—.01 rad/day.
2. Penetration of Van Allen Belts—out and back—1 rad.
3. Solar flare—Class III

a. In CSM—@ 5 gms/cm^2 35 rad depth dose E 100 MeV, (shielding considers both 5 gms/cm^2 of spacecraft material and 2.5 gms/cm^2 of body tissue).

b. In LM—@ 0.25 gms/cm^2 350 rads to the skin—100 rads to bone marrow.

TABLE I. RADIATION EVENTS ASSOCIATED WITH ENERGY RANGES

Energy Range	Representative Radiation Events
10 MeV	o^{al-}, etc.
10 MeV to 300 MeV	Spallation, fission, nuclear excitation followed by o^{al}, p, etc.
300 MeV to 1 BeV	Mesons, etc.
1 BeV	Mesons, electron—cascades, thindown events for heavy primaries
10 BeV	Build-up of secondaries

TABLE II. DOSE ESTIMATES BY ZONE (GENERAL)

	Galactic Background	South Atlantic Anomaly	Low Earth Orbit Non Anomaly	Inner Belt	Outer Belt	Synchronous Orbit	Solar Flare	Remarks
200 n.mi. Circular	0.01 rad/day	0.1-0.2 rad/day	0.01 rad/day	? Slight				Most manned missions will be flown below 200 n.mi.
600 n.mi. Circular	0.01 rad/day	0.3-0.6 rad/day	0.01 rad/day	5.3 rad/hour 0.66 rad/orbit				Unlikely manned orbit
Highly Elliptical	0.01 rad/day	0.6 rad/day		10 rad/hour** 6-8 rad/day 1-1.5 rad/orbit	2.0 rad/day		Umbrella effect	**800 × 6000 n.mi. Some secondaries
Synchronous Orbit	0.02 rad/day	Few mrad before orbit change		1-2 rad for transfer		1-2 rad/day Electrons X-rays Secondaries	≈ 30 rad	Secondaries become significant; electrons and X-rays add to skin dose
Lunar Mission	0.02 rad/day	Few mrad before translunar insertion		< 1 rad			Up to 35 rad depth dose @ 8 gm/cm^2	Skin dose in a lunar module ≈ 10 times higher

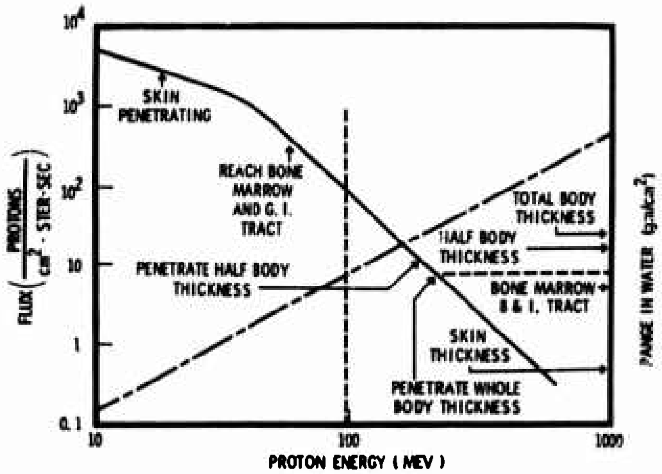

Fig. 4. Proton spectrum 15 November, 1960.

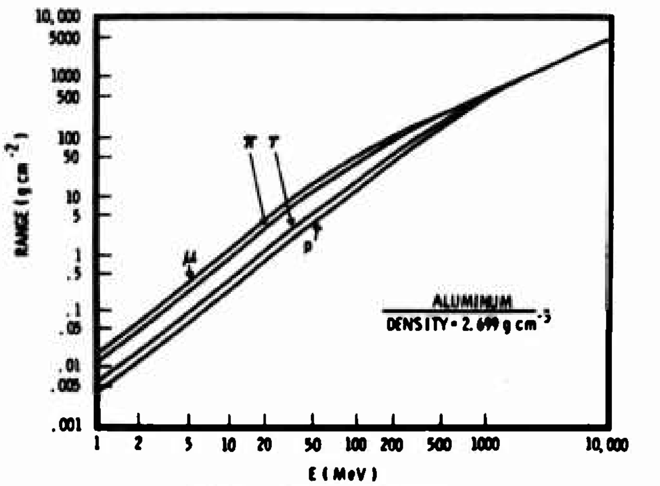

Fig. 5. Range vs. Energy.

c. On the surface of the moon—same as above.

4. Nonuniform dose distribution.

5. Protraction and fractionation are factors in average dose rate reduction.

6. Quality factor of 1 most likely average number to apply. (Quality factor, however, can be variable and significant).

7. Depth dose distribution becomes more important for flare cases.

8. Bremsstrahlung is also an important factor during parts of the mission.

9. Early effects other than possible malaise, nausea, and vomiting would reach their peak after mission completed (erythema is a possible exception).

On short duration (7 to 8 days) lunar missions, the radiation of consequence will be associated with a solar flare. Only Class III flares are of sufficient flux and energy to contribute a significant dose. This warrants concern for performance decrement in mission operations. Shielding will be a major factor in dose assessment because exposure in the CM will afford sufficient protection to stay well below demonstrable detrimental biologic effects. This, of course, is not true for exposure in the LM and/or the lunar surface suit. Here time of exposure and time after become paramount prior to evasive action and returning to the CM. In these latter two situations, sufficient dose to produce mild nausea and vomiting with associated anorexia is possible and as a consequence degradation in performance must be accepted. Other radiation responses, if any, would appear after the mission has been completed since most would occur 5 to 15 days postexposure, i.e., erythema, epilation, hematopoietic depression, etc.

TABLE III. 60-DAY MISSIONS (NONLUNAR)

Orbital Profile	Dose Rate	Energy	QF	Dose	Bio-Response
200 n. mi. circular					
Galactic	0.01 rad/day	High Energy Protons	1	0.6 rad	Few cell deaths
S.A. Anomaly	0.2 rad/day	High Energy Electrons	0.6	5.7 rad	No discernible effect
Nonanomaly	0.01 rad/day	Mid-Energy Protons	1	1.2 rad	
Elliptical					
Galactic	0.01 rad/day	High Energy Protons	1	0.6 rad	Few cell deaths
Anomaly	0.3-0.6 rad/day	High Energy Electrons	0.6	17.0 rad	Skin effects
Inner Belt	8-9 rad/day	Low Energy Electrons Mid-Energy Protons	0.6	32.0 rad	Soft tissue
Highly Elliptical					
Galactic	0.015 rad/day	High Energy Protons	1	0.9 rad	Few cell deaths
Anomaly	0.6 rad/day	High Energy Electrons	0.6	23 rad	Skin effects
Inner Belt	7.0 rad/day	Mid-Energy Protons, Electrons	0.6	274 rad	Soft tissue
Outer Belt	2.0 rad/day	Low Energy Electrons	0.6	75 rad	Skin effects
Synchronous					
Galactic	0.02 rad/day	High Energy Protons	1	1.2 rad	Few cell deaths
Transfer thru belts	1-2 rad/hr.	Mid-Energy Protons	0.6	1.5 rad	
Outer Belt	1-2 rad/day	Low Energy Electrons	0.6	37 rad	Skin and soft tissue
Flare	18 rad/day	High Energy Protons, and Alphas	1.25	37 rad/40 hrs	Depth dose
		LUNAR MISSION—8-DAY			
Galactic	0.02 rad/day	High Energy Protons	1	0.16 rad	Few cell deaths
Transfer thru belts	1-2 rad	Mid-Energy Protons Low Energy Electrons	0.6	1.0 rad	Skin and soft tissue
Flare	18 rad/day (CM) 350 rad (lunar surf.)-10 hrs	High Energy Protons High Energy Protons, Alphas	1.25	37 rad/40 hrs	Depth dose Skin dose

Dose Planning Factors

Consider the hypothetical but not unreasonable planning doses for Apollo and Apollo Applications (Lunar Exploration and related missions) to be set at 35 rad @ 5 cm depth dose for both acute and delayed effects and 350 rad @ 0.1 mm skin dose for both acute and delayed effects, then in light of the information contained in Tables I, II and III, a planning strategem can be developed.

LUNAR MISSION AND RELATED RADIATION STRATEGEM

Go-No-Go Phases of the Lunar Landing and Related Missions

The critical decision-making events to be considered in a lunar landing mission in terms of radiation dose criteria appear to be:

1. Lunar orbit insertion.
2. LM/CSM separation.
3. Initiation of Descent.
4. Lunar stay time.
5. Lunar excursion.
6. Ascent and rendezvous.

Conditions

A. The data base for go-no-go will in the main be derived from previous experiences, i.e., Mercury, Gemini, and/or ground simulations. Obviously, the only radiation experiences on healthy humans are limited to radiation accidents.

B. The go-no-go criteria applicable to the lunar crew will be based upon the biomedical assessment of crew condition and an acceptable radiation environment.

C. Go-no-go determinations based upon the above criteria can be satisfied by:

1. Crew biomedical telemetry.
2. Spacecraft radiation telemetry.
3. Radiation environment forecast.
4. Air-to-ground voice exchange with the crew.
5. On-board monitoring of crew radiation exposure.
6. Crew assessment of their own physical conditions and status.

D. Considering all of the above factors, the most reliable information on which to base sound judgments will come from on-board crew assessment and the spacecraft radiation detection instruments.

E. Once commitment has been made to descend to the lunar surface, it is really unimportant whether the preplanned mission was to be:

1. "Touch and go,"
2. Twenty-two and a half hours in duration, or
3. Thirty-five hours in duration.

F. The decision to abort should be based upon the estimated absorbed dose to the astronauts and the time course of clinical symptomatology. For example, in the simplest case of "touch and go" from touchdown through checkout, ascent and rendezvous, the minimum time is about 5½ hours assuming no prolonged EVA is required. Thus, the most significant information will come from the individual crew member's assessment of his condition; specifically, does he manifest signs and symptoms of malaise, anorexia, nausea, and/or vomiting. These are the only clinical symptoms that could be observed over this time period, and vomiting would be the only symptom indicative of a substantial decrement in performance. One's decision here should be based upon the time required for subsidence of the effect prior to executing the delicate maneuvers involved in ascent or the time involved for preparation of extravehicular activities. (See Activity Time-line, Figure 6.)

G. If radiation exposure occurred at times other than those mentioned above, there would be sufficient time to determine crew condition and status, i.e., postlunar orbit insertion, during sleep, and the other periods prior to LM/CSM separation, for here again the presence or absence of vomiting should be the actual basis for deciding crew activity postexposure.*

*It should be emphasized that Class III solar flares are the only ones of real concern. Since event size is reasonably well known after 4 hours and since this is the 'max for vomiting, it would appear that the first 4 hours following any radiation exposure represent the threshold time for judgment. Anything less would most likely be based upon emotion and unsubstantiated evidence.

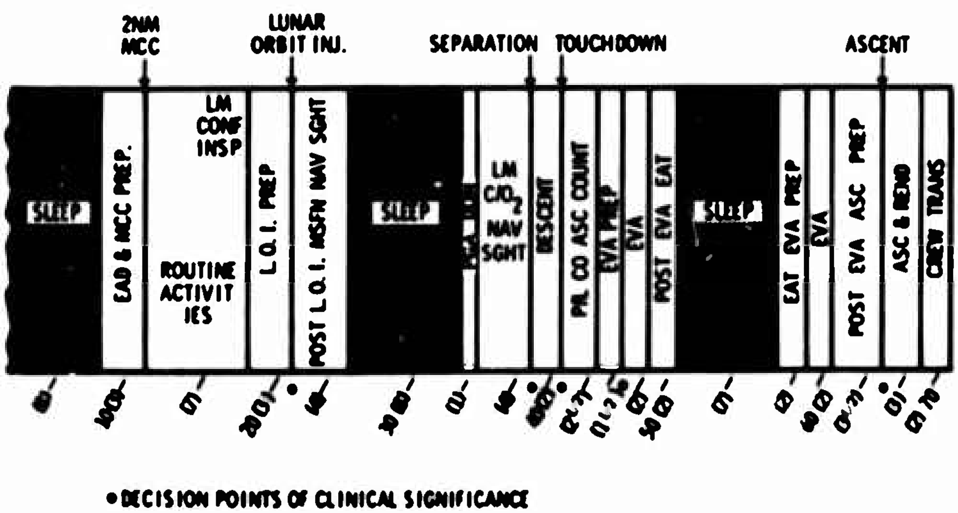

Fig. 6. Activity timeline.

Clinical Judgments

Clinical radiation dose criteria when viewed in the context of existing human observations, i.e., radiation accidents at Los Alamos, Oak Ridge, Argonne, Yugoslavia, Russia, Rongelap, Utirik, Ailingnae, and Rongerik, and neglecting therapeutic cancer patients, can be of value in go-no-go decision making.

Lunar Mission of Short Duration (7 to 8 days)

Observations following accidental exposure to healthy persons indicate that nausea and vomiting do not occur below 120 rad, and vomiting alone does not occur with doses less than 180 ± 5 rad; (one exception). If one assumes the first lunar missions are to be accomplished within a 7 to 8 day time period and if one argues that the *only real contribution* of radiation dose would be associated with a solar flare, the only biological responses following a flare, that could obtain in this time period (7 to 8 days) would be malaise, anorexia, nausea, vomiting, a slight drop in lymphocytes, and the remote possibility of erythema (if exposed on the lunar surface or in the LM). All other responses take longer than 7 days. Furthermore, it might logically be argued that a dose of 35 to 80 rad is a maximum should the exposure occur in the CM. The larger dose would be in the exercise of a contingency plan where additional exposure to accomplish evasive action, retrieve an integral element of the mission, or conclude mandatory operational procedures yield gains far in excess of the risk from radiation since each of these judgments would be directed to enhancing all other aspects of mission safety! Such being the case, then one would only expect malaise, maybe anorexia, and no nausea, thus slight, if any, decrement in performance. Vomiting in all likelihood would not occur from *radiation* and even if it did (i.e., from anxiety), evidence indicates it is by and large confined to the first 4 hours postexposure. Thus it would not unduly complicate the return mission. Any hematolgic depression, if at all measurable, would occur after the mission where supportive therapy, if indicated, could be administered. Thus, one can conclude that for lunar missions, which spend but a short period of time in the anomalous region and very little more in penetrating the Van Allen Belt, there is no real acute radiation response constraint. Once again, one is obliged to evaluate the long term delayed effects. The total dose in the CM is below the cataractogenic dose level, it is insufficient to produce skin effects suggestive of skin carcinoma, but statistically and/or actuarially might contribute to a shortening of life span. In regard to these two latter constraints, however, it must be remembered that the hazards of normal military flying also shorten the life expectancy of an airman.* Although there will never be enough astronauts to show statistically an increase above the spontaneous rate for leukemia, it must be considered as a remote possibility.

If exposure occurs on the lunar surface as a result of a solar flare, then one would predict an erythema most likely after the mission was completed, i.e., 5 to 10 days postexposure, unless the skin dose exceeded 570 rad.

Low Earth Orbit

For missions of 60 days or less in orbits below 200 n.m., an astronaut will receive about 25 rad of radiation which in this case will be of moderately low energy. Furthermore, since this is a superficial surface dose of radiation, then one will *not* see the symptoms of malaise, anorexia, nausea, vomiting, diarrhea, erythema, or epilation for reasons of dose versus effect. Similarly, one could not measure the usual hematologic response other than perhaps very subtle changes presumed to be associated with low doses of ionizing radiation, i.e., chromosome abberations. Whether or not long term delayed effects would ever be manifest with such doses would be based solely on the statistical and/or actuarial predictions of the moment. It is questionable if there is any human data to substantiate an increased incidence of leukemia and/or a shortening of life span at this low dose (25 rad). Similarly, such dose levels are well below cataractogenic dose limits. In fact, it is doubtful if any vacuoles and/or opacities could be observed. Variable dose rates, nonuniformity of dose, little depth of penetration, dose protraction, the quality factor one would apply to the low energy protons, and the beta particles in the South Atlantic Anomaly all tend to reduce the effective radiation dose values. This same argument holds for higher circular orbits up to stay times of 60 days. For circular orbits up to one year duration, it would be necessary after the exact orbit has been established to exercise caution for reasons of possible skin effects. In all likelihood, the protraction and fractionation of dose again would tend to discount even this effect, except for the long term delayed situation (several years postradiation). Here it is possible but not very probable that skin cancers could form, but the region for this concern is at the moment higher than altitudes being planned for the AAP missions.

This must be qualified, however, by the statements: If EVAs are properly programmed, if no particles are added to the anomaly from high altitude nuclear testing, and if orbital altitudes are not changed upward, i.e., 400 to 500 n.m., for many days. As the orbit goes up in altitude, i.e., 400 to 500 n.m., there is sufficient time spent in the more intense region of the anomaly and the fringes of the inner Van Allen Belt to markedly increase exposure to the skin. In this specific case, a skin dose could accumulate to produce mild transient *erythema* and as a consequence slight discomfort.

For the high circular (600 n.m.) and the highly elliptical cases (600 to 6000 n.m.) until more refined measurements are available, little else need be said than skin doses may accumulate above the threshold for erythema and for that matter dose rates could exceed the planning figures, albeit this is a strict function of orbital altitude and inclination. Thus, discomfort would limit performance. In synchronous orbit, the dose rates are with present information marginal, to

*Of the 66 astronauts chosen to date, 16 are already out of the program (9 by accidental death and 7 from some medical, physiological, or other reason).

the extent that shielding factors could indeed be the difference for 60-day stay times. (See Figures 4 and 5.) Slight differences in shielding, even to the degree of protection afforded by partial body shield (i.e., radiology aprons and/or water-cooled undergarments) could make the difference. This is not only true for the primary dose, but equally true for some of the secondaries produced from electrons. Parenthetically, it should also be stated "in the absence of a solar flare," for at synchronous altitudes any umbrella effect from the radiation belt is negligible.

Each proposed mission profile for the future should be examined against what is to be accomplished by man in each of the radiation zones, and sound criteria presented. Generalizing as we have in the past concerning radiation doses and projected effects has in many instances created "straw men." The rationale by which planning and mission doses are developed should be viewed, justified, and accepted with the full realization that in the conquest of any unknown, complete understanding and interpretation are not unequivocally apparent until after the fact. Best judgment, careful scientific interpretation of existing data can and does, however, permit man to continue to delve into the unknown in a conservative and sensible way and at the same time maintain the risk versus gain philosophy in its proper perspective. Radiation is but one of the serial risks of space flight. It should get its full consideration, but must be viewed against the total mission risk. Thus, preplanning the conservation of radiation dose against proposed missions, considering the age of astronauts, and at the same time maximizing the talent and experience of individuals, bring to the decision-makers an opportunity to operate on a less-than-chance basis. Each flight and its radiation cost can, in general, be determined before the fact. Similarly, then, recurring missions, taking into account the specific talents of each astronaut, be he a test pilot, astrophysicist, or physician, can be programmed and flown against experiments to be performed.

REFERENCES

1. Dalrymple, G. V., and I. R. Lindsay: Protons and space travel—An introduction. *Radiat. Res.* 28:365-371, 1966.
2. Gerstner, H. B.: Reaction to short-term radiation in man. *Ann. Rev. Med.* 11:289-302, 1960.
3. Harris, M. D., *et al.*: OV3-4 Satellite. Air Force Weapons Laboratory, Albuquerque, NM. Personal communication.
4. Langham, W. H.: (Ed). Radiobiological factors in manned space flight. National Academy of Sciences, National Research Council Publication 1487: pp. 274, 1967.
5. Manned Spacecraft Center, Houston, Texas: Gemini Summary Conference, NASA SP-138: p. 345, 1967.
6. Manned Spacecraft Center, Houston, Texas: Science and Technology Advisory Committee Briefing. Lunar Landing Mission, Part. 3. "Working Papers" 1967.
7. Pickering, J. E., R. G. Allen, Jr., and O. L. Ritter: Problems in shielding. Medical and biological aspects of the energies of space. Columbia University Press 381-390 1961.
8. Rose, R.: Manned Spacecraft Center, Houston, Texas. Personal communication.

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas	Unclassified
	2b. GROUP

3. REPORT TITLE

RADIOBIOLOGICAL CONCEPTS FOR MANNED SPACE MISSIONS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

John E. Pickering, Colonel, USAF

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1970	7	8

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
b. PROJECT NO.	SAM-TR-70-267
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
Aerospace Med. 41(2): 159-165 (1970)	USAF School of Aerospace Medicine Aerospace Medical Division (AFSC) Brooks Air Force Base, Texas

13. ABSTRACT

Carefully established premission planning doses and maximum operational dose limits are clearly enhanced by clinical judgments when go-no-go decisions are made in the event of an astronaut's exposure to ionizing radiation. The very nature of extended lunar missions (exploration) and long duration low earth orbit missions are clear cases for evaluating man's clinical response before go-no-go decisions are made. There are well identifiable decision points in mission plans that are best judged by clinical responses if the mission is to avoid performance decrement at critical times, i.e., at the peak of astronaut activity: descent, EVA, ascent, rendezvous, transfer, etc. Careful on-board monitoring of the astronaut's condition and judicious recording and interpretation of actual radiation manifestations with respect to time can and should dissuade premature or unfounded decisions. This philosophy has its greatest merit if one accepts the tenet that man is in the system to make observational judgments and assessments.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Manned space flights						
Lunar missions						
Ionizing radiation						
Radiation response						